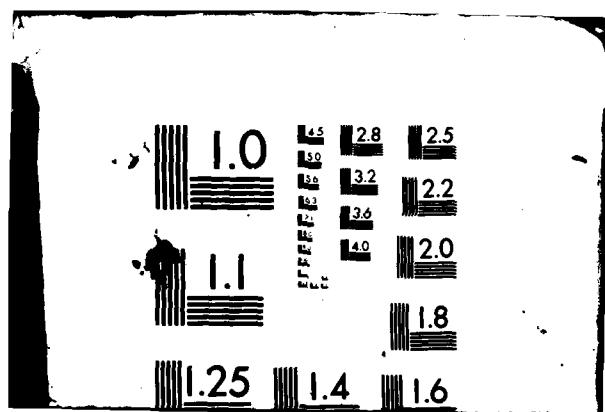


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**TECHNICAL REPORT**

WSRL-0233-TR ✓

**THE DESIGN OF A PORTABLE ALL ARMS CALCULATOR (PAAC)**

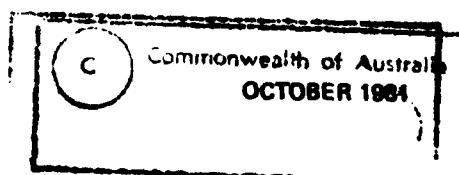
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TECHNICAL REPORT

WSRL-0233-TR

THE DESIGN OF A PORTABLE ALL ARMS CALCULATOR (PAAC)

C.J.P. Bensted

S U M M A R Y

A microprocessor based calculator is described which has been designed to provide assistance in determining aiming coordinates for Mortar fire control. However by changing the keyboard overlay and the software the calculator can be used for a variety of applications including Artillery and Armour fire control.



POSTAL ADDRESS: Chief Superintendent, Weapons Systems Research Laboratory,  
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## 1. INTRODUCTION

In 1977, Army Office issued Army Staff Requirement (ASR) 48.3 which described the Infantry's need for a calculator to carry out technical fire control tasks. The Weapons Systems Research Laboratory (WSRL) and the Electronics Research Laboratory (ERL) of the Defence Science and Technology Organisation (DSTO) jointly produced a small hand held calculator code named ELMOR (ELevation of MORTar), to demonstrate the feasibility of developing such a device in Australia. Whilst ELMOR provided an indication of the capability of small special purpose calculators using the technology existing at that time, it was clear that with assistance from the Army, a calculator with more widespread fire control application could be designed.

Consequently, a Portable All Arms Calculator (PAAC) was considered as a technical objective with users being primarily the Infantry, Artillery and Armour. In view of the recent experience gained by the DSTO in preparing ELMOR for Army evaluation, it was decided that the mortar application of PAAC should be considered before the others. Having assessed ELMOR in the field and at the Infantry Centre, the Army was able to provide the DSTO with a number of recommendations that might be considered in the further development of a fire control calculator.

In early 1980, the DSTO decided to produce advanced demonstration models of PAAC which could be evaluated by the Army in order to assess the viability of an All Arms approach. This report describes the design of the advanced demonstration model. The mortar fire control software was developed by staff from Ballistic Studies Group, WSRL.

## 2. GENERAL DESCRIPTION

The calculator is a hand held unit about the size of a medium sized book. It has a liquid crystal display (LCD) on which thirty two alpha-numeric characters, arranged in two rows of sixteen characters, can be displayed. It also has a keyboard consisting of forty keys placed in an 8 x 5 matrix arrangement. Photographs of the completed calculator are shown in figures 1, 2 and 3.

The unit is battery powered using rechargeable nickel-cadmium batteries but provision has been made for the use of external power if required. The batteries can be changed while the calculator is in use. Low power standby batteries are provided which retain, during main battery changeover, all data previously entered into volatile memory. These standby batteries are trickle charged from the main batteries which have to be recharged using an external charger. Provision has been made for warning the operator when the main battery voltage has reached a lower limit by flashing the display during the last approximately thirty minutes of the life of the batteries.

An additional feature of the calculator is the provision of a serial interface so that the calculator can be connected to, and communicate with, external computing or display equipment. This interface uses the internationally recognised RS232C communication protocol.

The circuit design of the calculator uses low power CMOS components wherever possible. No suitable CMOS microprocessor was available when this circuit was developed. However, it was known that a microprocessor manufacturer was intending to market in the near future a CMOS processor, known as the NSC800 (see Reference 1), which would use the same instruction set as the NMOS Z80 processor which was readily available. The design of the calculator was therefore based on the Z80 processor and software has been written using its instruction set. This design is therefore an interim design and it is

anticipated that any further models of this calculator, that may be produced, would be redesigned to use the NSC800 processor and its associated interface devices.

### 3. MICROPROCESSOR CIRCUIT

The calculator is based on a Z80A microprocessor driven by a 3 MHz clock and a block diagram of the unit is shown in figure 4. The microprocessor has been provided with thirty-two kilobytes of erasable programmable read only memory (EPROM) for program storage and four kilobytes of read/write memory or random access memory (RAM) for data storage. The EPROM occupies the address space 0000 to 7FFF, using the hexadecimal notation, and the RAM is at F000 to FFFF.

Two interface devices are connected to the microprocessor namely an 8255A parallel peripheral interface (PPI) unit, for driving the 32 character display and reading the 40 key keyboard, and an 8251A serial interface unit to allow communication between the microprocessor and external equipment. The microprocessor also has a second PPI unit for connection to an MM57109 mathematical processor integrated circuit (IC). This processor was included to perform the mathematical computations required in determining aiming coordinates. This computation can be done much faster in software but this processor was included in the design to simplify the initial task of writing software for mortar fire control. The mathematical processor and the parallel port unit will be removed when the appropriate software package performing the same function has been written.

The circuits shown in figures 5, 6 and 7 which were used to connect the microprocessor to its memory and interface devices are standard and examples are readily found in manufacturers literature(ref.2,3) so no further description will be given here. The 8255A PPI interface circuits are described in detail in subsequent sections. The 8251A device can be used as an RS232C interface. However, no buffering of the device input or output signals has been provided. It is anticipated that any buffering required would be provided by the host system to which the calculator is connected. Transmit and receive clock signals for this interface will also be provided by the host equipment.

### 4. DISPLAY UNIT INTERFACE

A circuit diagram of the display unit interface and the keyboard interface is shown in figure 8. The display interface is controlled by Port A and the upper half of Port C of an 8255A PPI unit. Port A is used to output data in the form of ASCII characters to the display RAM (IC5 and IC9).

Port C bit 7 is used to control the display unit. When PC7 is a '1' the display unit is disabled and an updated message can be written to the display RAM. When PC7 is a '0' the display unit will read the RAM via the address lines AA0 to AA4 inclusive and use its clock signal ( $\phi_c$ ) to output the contents of each memory location onto the address lines of the character generator circuit (IC1). The output of the character generator in the form of row and column information is then read by the display circuit using the S1 to S3 and the DC1 to DC5 lines.

Port C bit 6 is used by the microprocessor to reset the counter (IC6) to zero at the start of the sequence which writes a new message to the display RAM. The counter is used to provide an incrementing address to the display RAM via the tri-state buffer (IC2) which is enabled by PC7.

Port C bit 5 is used to clock the counter (IC6) by one count thereby

incrementing the address to the display RAM. Port C bit 4 is used to write the character, which has previously been set up on the Port A lines, into the display RAM.

The sequence of events which occur when the display sub-routine is accessed by the microprocessor can be summarised as follows:

- (a) Establish a '1' on the PC7 line, ie, disable the display
- (b) Zero the display counter (IC6) by sending a pulse on the PC6 line
- (c) Establish a character on the Port A lines
- (d) Write the character into the display RAM (IC5 and IC9) at the address set up by the counter (IC6) by sending a 50 microsecond pulse to the PC4 line. (This pulse must have a minimum duration of 50 microseconds to ensure that a clock signal ( $\phi$ c) occurs during the writing period).
- (e) Check to see if 32 characters have been sent and if so jump to step 'h'
- (f) If not, increment the counter (IC6) by sending a pulse on the PC5 line
- (g) Jump to step 'c' to write next character
- (h) Establish a '0' on PC7 to allow the display unit to read the display RAM and exit the subroutine.

When the display unit is enabled, by the PC7 line being set to a '0' it will continually read the display RAM at a rate determined by its internal clock signals so that the 32 characters are continuously displayed.

##### 5. KEYBOARD INTERFACE

The keyboard consists of a matrix of 40 normally open switches which can be pressed by the operator. These switches are set up in the form of 5 columns of 8 switches each. Port B lines 0 to 4 are used by the microprocessor to interrogate each column of switches in turn. The lower half of Port C is used to read the switches in the appropriate column to ascertain which switch has been pressed.

ICs 3 and 7 are wired to provide an 8 bit priority encoder the output of which, in binary coded decimal format, is read via the gates in IC11 by the lower half of Port C.

The 'keyboard read' subroutine establishes a '0' on the PB0 line and '1's on the PB1 to PB4 lines thereby interrogating the first column. The PC0 to PC3 lines are then read by the microprocessor to see if a switch has been pressed in that column. If it has then the processor exits the subroutine taking with it the identification of the switch which has been pressed. If no switch has been pressed in that column then PB0 is set to a '1' and PB1 is set to a '0' and the next column of switches is interrogated. This process is repeated for all five columns if necessary. The processor will exit the subroutine as soon as it finds a switch pressed. In this way there is no confusion if two switches are pressed at the same time as the processor will only 'see' one of them.

## 6. MATHEMATICAL PROCESSOR INTERFACE

The mathematical processor was included in the calculator design to provide the mathematical computation functions required. Also it eliminated the need for software to be written to provide the same complex mathematical functions. However it performs these functions much slower than would an equivalent software package. It is intended that this processor and its interface will no longer be used when equivalent software has been developed.

The circuit of the mathematical processor interface is shown in figure 5 and comprises ICs 3, 4, 5, 6 and 8. An 8255A (IC4) is used to interface the microprocessor to the mathematical processor (IC5). A triple inverter oscillator circuit (IC3) is used to provide a 400 kHz clock signal for IC5 which also requires a negative voltage supply (ICs 12, 13, 14). Port A is used to provide instruction codes to the processor and Port B is used as a bi-directional binary coded decimal (BCD) data path. IC6 is used as a voltage level translator for the 'power on reset' and 'hold' signals. IC8 is a dual flip-flop used to temporarily store the 'branch' and 'digit address strobe' signals developed by the mathematical processor so that the central processor can 'read' them at a convenient time.

The function of, and the programming for, the mathematical processor is quite complex and it is not practicable to further describe it in this note. Complete details of the operation of the mathematical processor are given in reference 4.

## 7. POWER SUPPLY

The calculator is powered by four 'D' size nickel-cadmium batteries which provide the nominal 5 volts supply required by the semiconductor devices. These batteries are rechargeable and have a capacity of four ampere-hours which is sufficient for the calculator to be used continuously for up to eight hours. This duration will be extended to at least ten hours when the mathematical processor device and its associated interface circuit is removed and replaced by a software package performing the same function.

The display unit also requires a minus 5 volt supply and this is provided by ICs 12, 13 and 14 (figure 5). Three devices are required, connected in parallel, to supply the necessary current.

Provision has been made for operating the calculator using external power, for which a socket has been provided (figure 9), and for detecting low battery volts. The low battery voltage circuit is shown as part of the RAM circuit diagram (figure 6). The voltage comparator (IC8) compares a voltage, which is derived from a potential divider connected across the battery supply, with a reference voltage developed by IC7. When the voltage is less than the reference voltage, the voltage comparator triggers the timer unit IC1 which interrupts the processor to indicate low battery voltage. The timer can then interrupt the processor after a fixed time interval to remind the operator that the battery volts are still low. The battery voltage at which this circuit trips is set to indicate that there is approximately thirty minutes battery life remaining after the first interrupt occurs.

## 8. CONSTRUCTION

The calculator is fabricated from a polypropylene compound which is similar to the compounds that might be used in production using injection moulding techniques. The case produced is about three times as light in weight as an equivalent case manufactured from aluminium. In this instance the case was

milled from a solid piece of the polypropylene compound as only a few cases were required.

Separate compartments are provided for the electronic cards, the main batteries and the standby batteries. Access to the battery compartments is provided by means of recessed aluminium covers which are screwed in place but which can be removed without the aid of special tools. A recessed push-button switch is provided to switch the calculator ON and OFF and two connectors (military specification) are fitted, one to allow connection to an external power source, and the other for the serial data interface.

The thirty-two character LCD display unit is fitted at the top of the front panel of the calculator and covered with an anti-glare filter. This display and filter assembly is sealed into the case to prevent the entry of moisture.

The keyboard, which is below the display and occupies the remaining front panel space, consists of two five by four flexible membrane switch matrices connected to form an eight by five keyboard. A clear plastic overlay on which the key functions are annotated, covers the keyboard and is held in place by means of a black anodised aluminium grill which physically defines each key position. The keyboard is also sealed against the entry of moisture. The overlay and the grill which holds it in place is easily removed to allow the fitting of an alternative overlay so that the keys can be assigned different functions for different applications.

The electronic cards and the display module are fitted into the calculator from the rear. The electronic cards plug into each other and the program memory card (figure 7) is removable to allow for software changes for different applications of the calculator. The removable back cover has a gasket which seals the calculator against the entry of moisture.

The calculator including batteries weighs approximately two kilograms.

#### 9. CONCLUSION

The calculator described in this report is an advanced demonstration model which could go into quantity production without much modification. However it is heavier than one would wish and a longer battery life of at least 20 hours would be most desirable. It is known that lower power components will shortly become available which will allow the weight to be reduced and the battery life extended. This improvement in performance can be achieved with a minimum of redesign to either the circuit or the software as it is anticipated that the lower powered microprocessor will use the same instruction set.

#### 10. ACKNOWLEDGEMENTS

The author wishes to acknowledge the assistance of Mr S.G. Johnson who coordinated the project and was responsible for liaison with the Army Office. He also wishes to acknowledge the considerable assistance given in the mechanical design and production of the calculator by Mr A.D. Hind and Mr R.L. Thornton who were also responsible for the procurement of components, production of printed circuits and assembly and testing. The assistance of Mr A.I. Ware, who was responsible for the production of the case and battery fittings is much appreciated.

## REFERENCES

No.	Author	Title
1	-	NSC800 Microprocessor Family Handbook 1980 National Semiconductor Corporation
2	-	MCS-80 User's Manual 1977 INTEL Corporation
3	-	Microcomputer Components Data Book February 1980 Zilog, Inc
4	-	MM 57109 MOS/LSI Number-Oriented Microprocessor 1977 National Semiconductor Corporation

GLOSSARY OF TERMS

ASCII	American National Standard Code for Information Interchange among data processing systems. Uses a coded character set consisting of 7 bit coded characters.
BINARY CODED DECIMAL (BCD)	A binary numbering system for coding decimal numbers in groups of four bits.
BIT	A circuit element which can only be stable in either of two states. One state is known as a '1' and the other as a '0'. A binary digit.
BYTE	A sequence of eight adjacent bits operated upon as a unit.
CMOS	A technique for integrated circuit manufacture known as 'complementary metal oxide silicon'.
EPROM	Erasable Programmable Read Only Memory. A data storage element, the contents of which can only be 'read' by the microprocessor and not altered by it. Data can only be altered by erasure followed by re-programming.
HARDWARE	The electronics and components of any computer or microprocessor which are hard physical objects.
HEXADECIMAL	A numbering system using the numbers 0 to 9 and the letters A to F to identify the sixteen numbers that four binary digits (bits) can have.
INTERRUPT	A hardware system which enables a program being executed by the processor to be stopped temporarily, while an alternative program is executed, and then resumed when the alternative task is completed.
NMOS	A technique for integrated circuit manufacture known as 'negative channel metal oxide silicon'.
PORT	An input or output route for transferring data or information to or from a system.
PPI	Parallel Peripheral Interface. A name given by one manufacturer to an integrated circuit used to 'input' or 'output' data to or from a microprocessor system.
PRIORITY ENCODER	A circuit which encodes a digital signal appearing on one of several lines into a parallel binary word, giving priority to that signal which first appears on these lines.
RAM	Random Access Memory. A data storage element, the contents of which can be 'read' or altered by the microprocessor by choosing an address randomly.

RS232C	A specification for an internationally recognised method of serial data communication between digital systems.
SOFTWARE	A set of instructions for the operation of a computing system which are changeable for different applications of that system.
TRI-STATE	A circuit element which has the characteristic that it can either be a high level or a low level or it can present a high resistance to its output line effectively rendering that line open-circuit.
USART	Universal Synchronous Asynchronous Receiver Transmitter. An integrated circuit designed for use in serial digital data communication systems.



Figure 1. The Portable All Arms Calculator

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Figure 2



Figure 2. Calculator and Demonstration Carrying Case

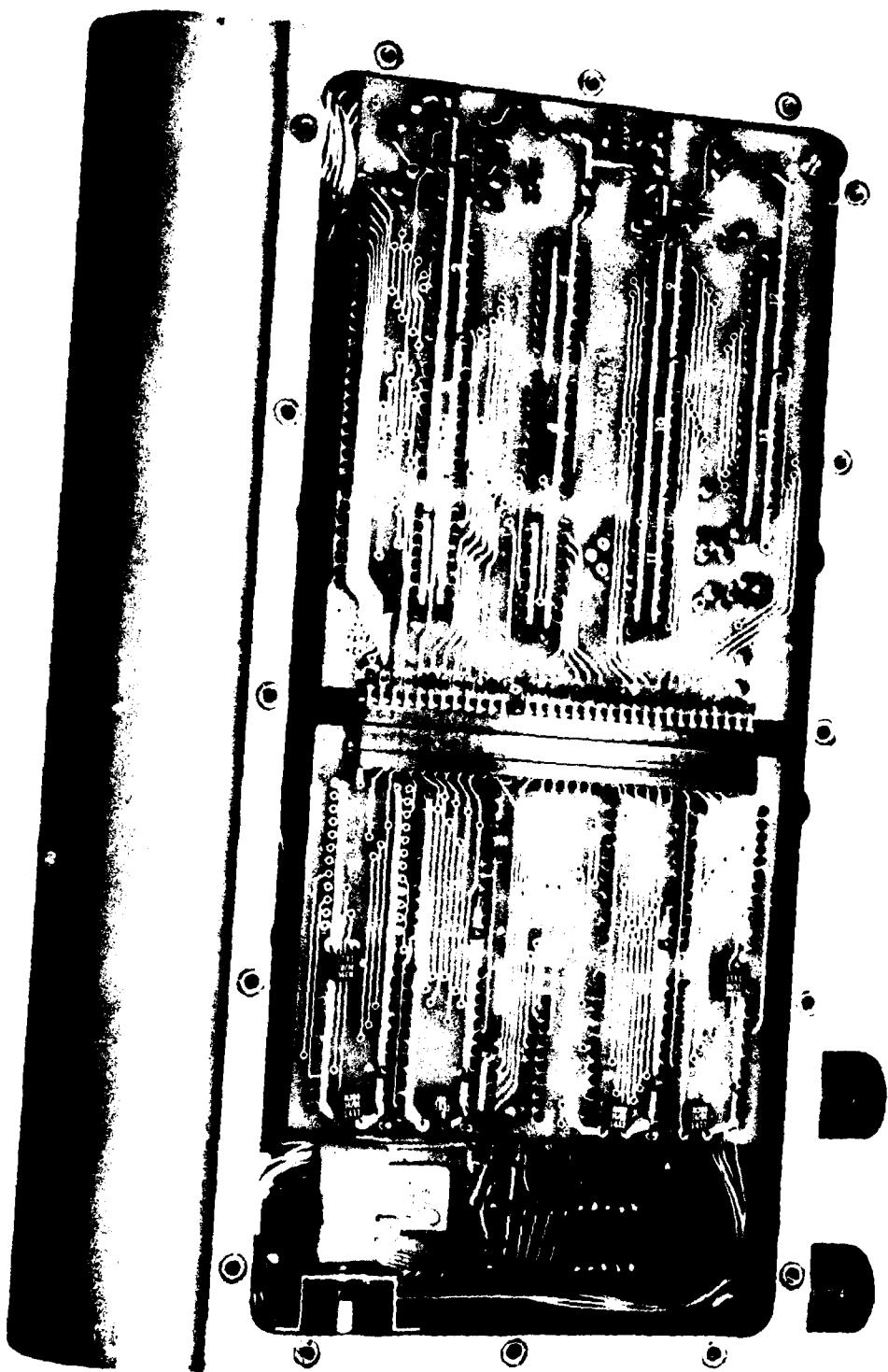
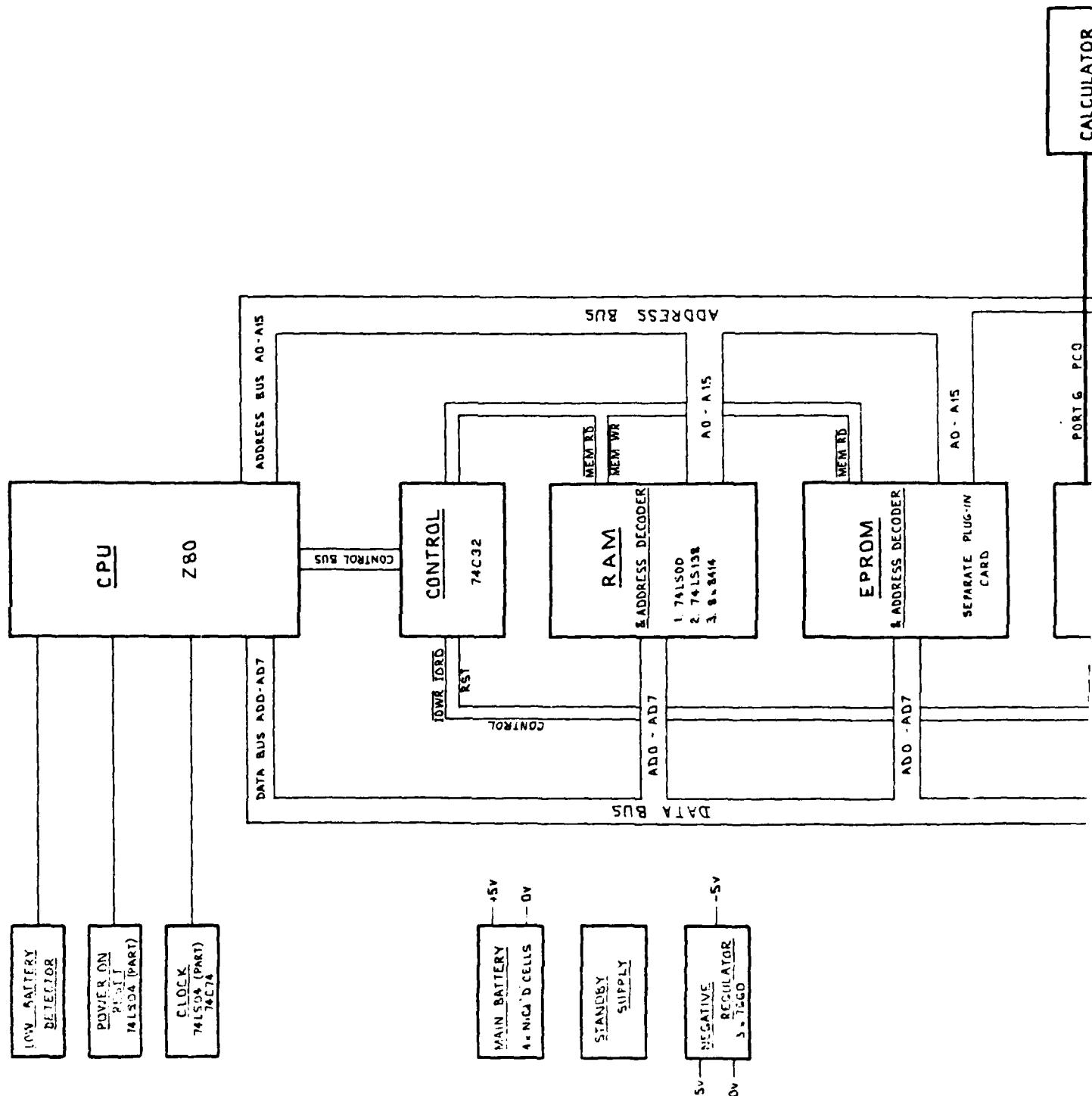


Figure 3. Internal Construction of the Calculator



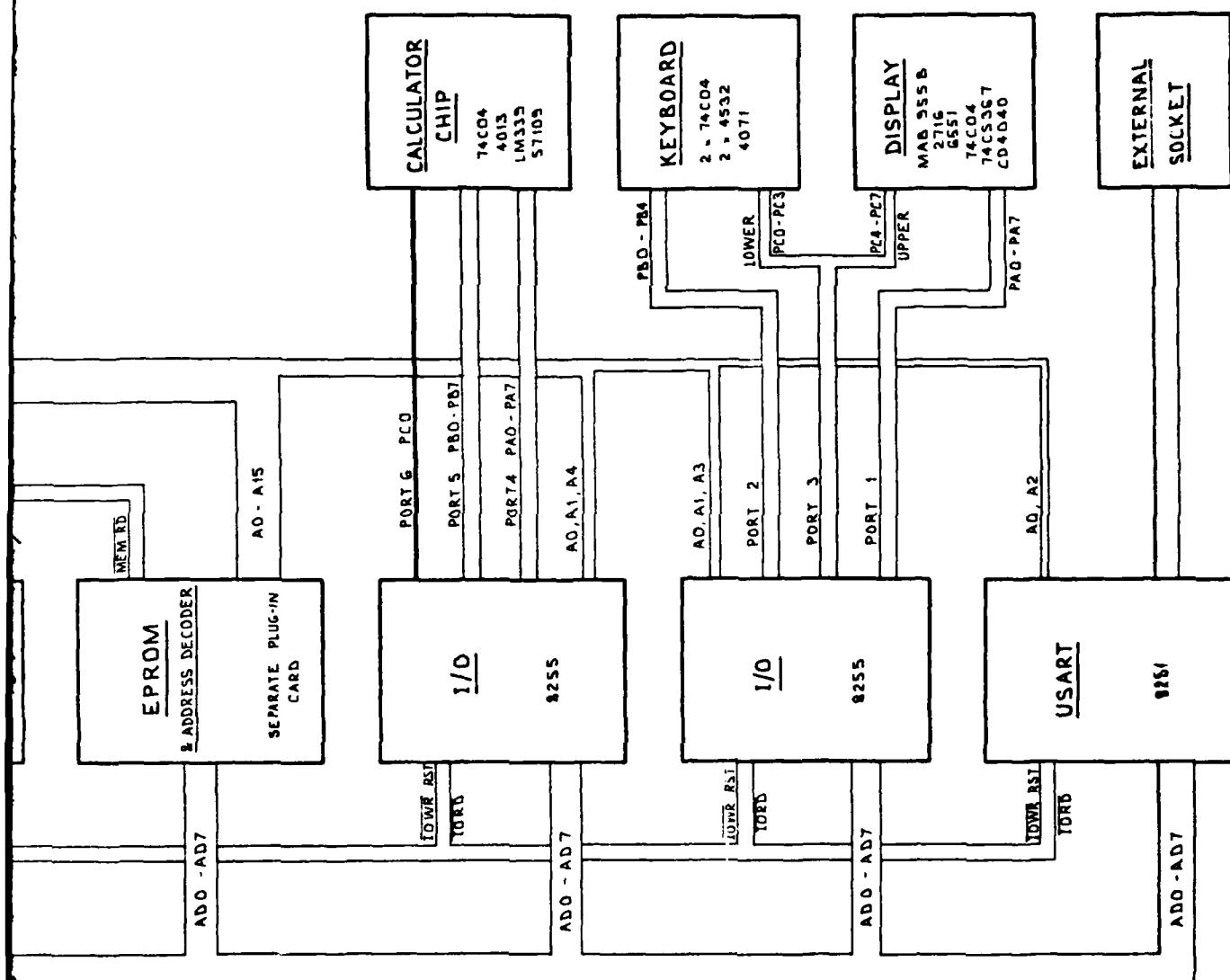
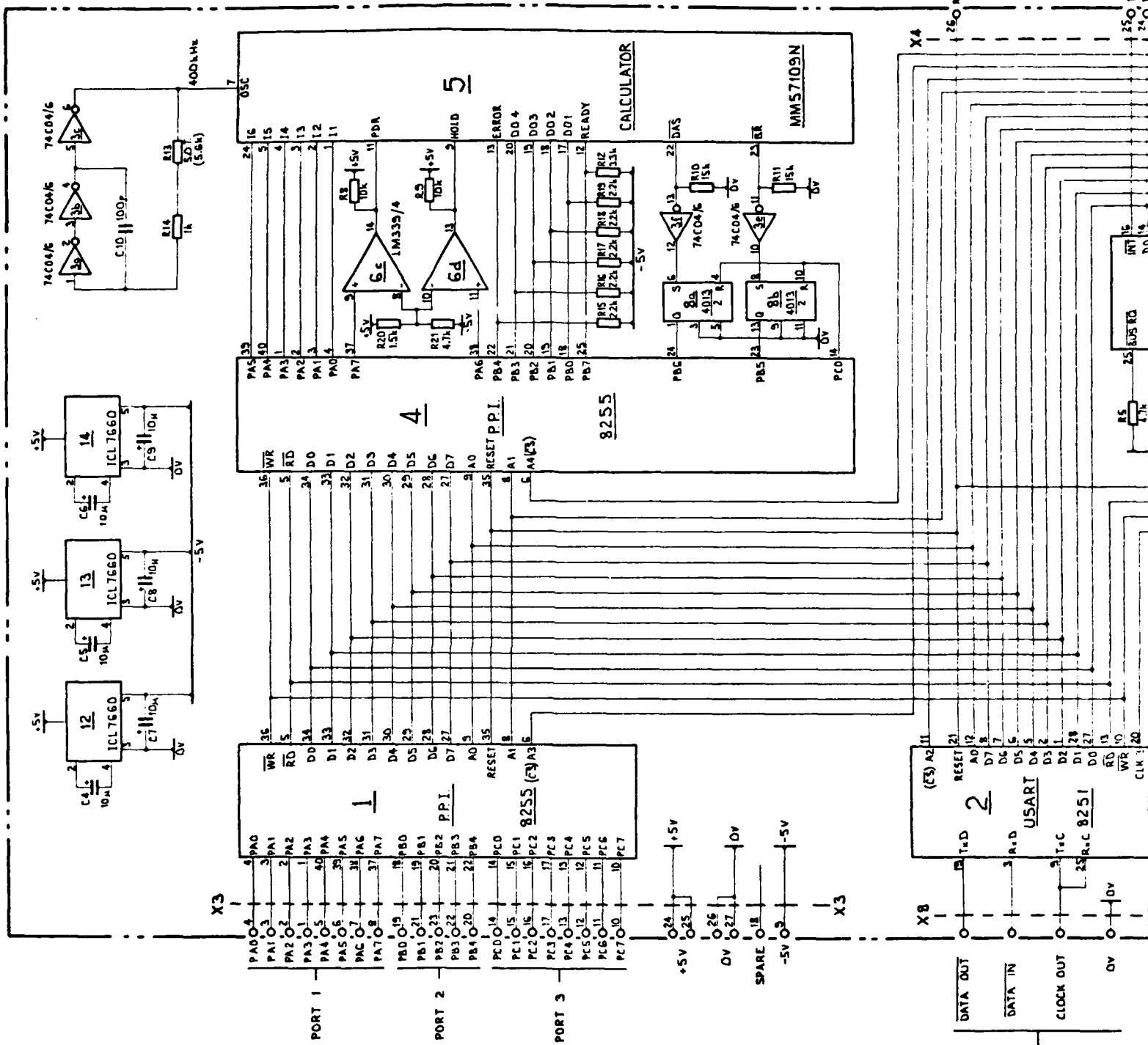


Figure 4. Block Diagram

Figure 5



REF N°	TYPE	DESCRIPTION	NO OF PINS	+5V	0V
1,4	8255	I/P	40	26	7
2	8251	USART	28	26	4
3	74C04	HEX INVERTER-SLEEFER	14	14	7
5	74LS181	CALCULATOR	23	15	—
7	74LS32	INTEGRATOR	4	3	—
8	74LS1	FLIP FLOP	16	14	7
9	74LS14	FLIP FLOP	16	14	7
10	200	CPU	40	11	29
11	74LS131	QUASI 2-10 OR	14	14	7
12-13-14	74LS100	LOGIC INTEGRATOR	8	8	3
15	74LS14	DECODE INTEGRATOR	14	14	7

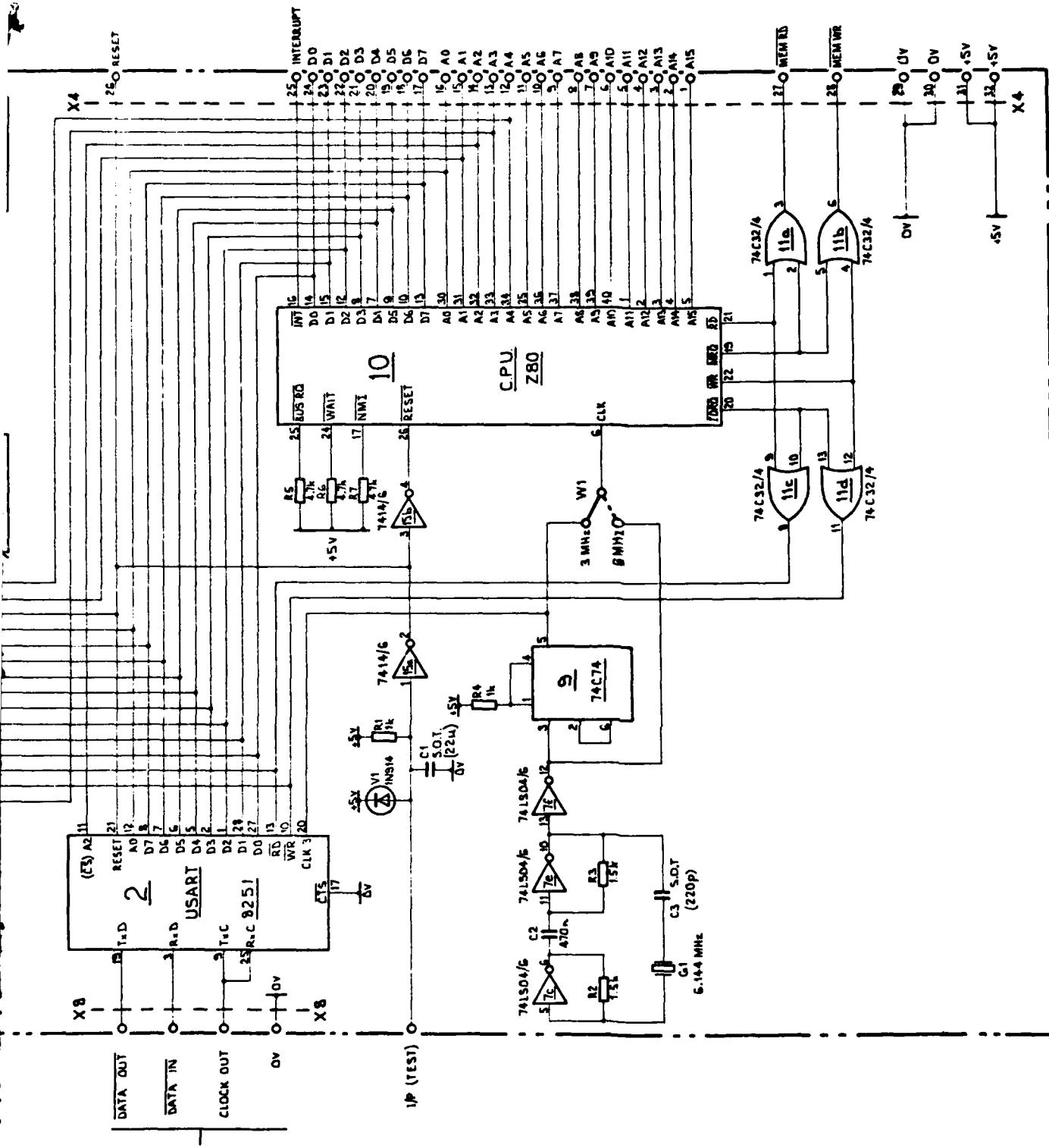
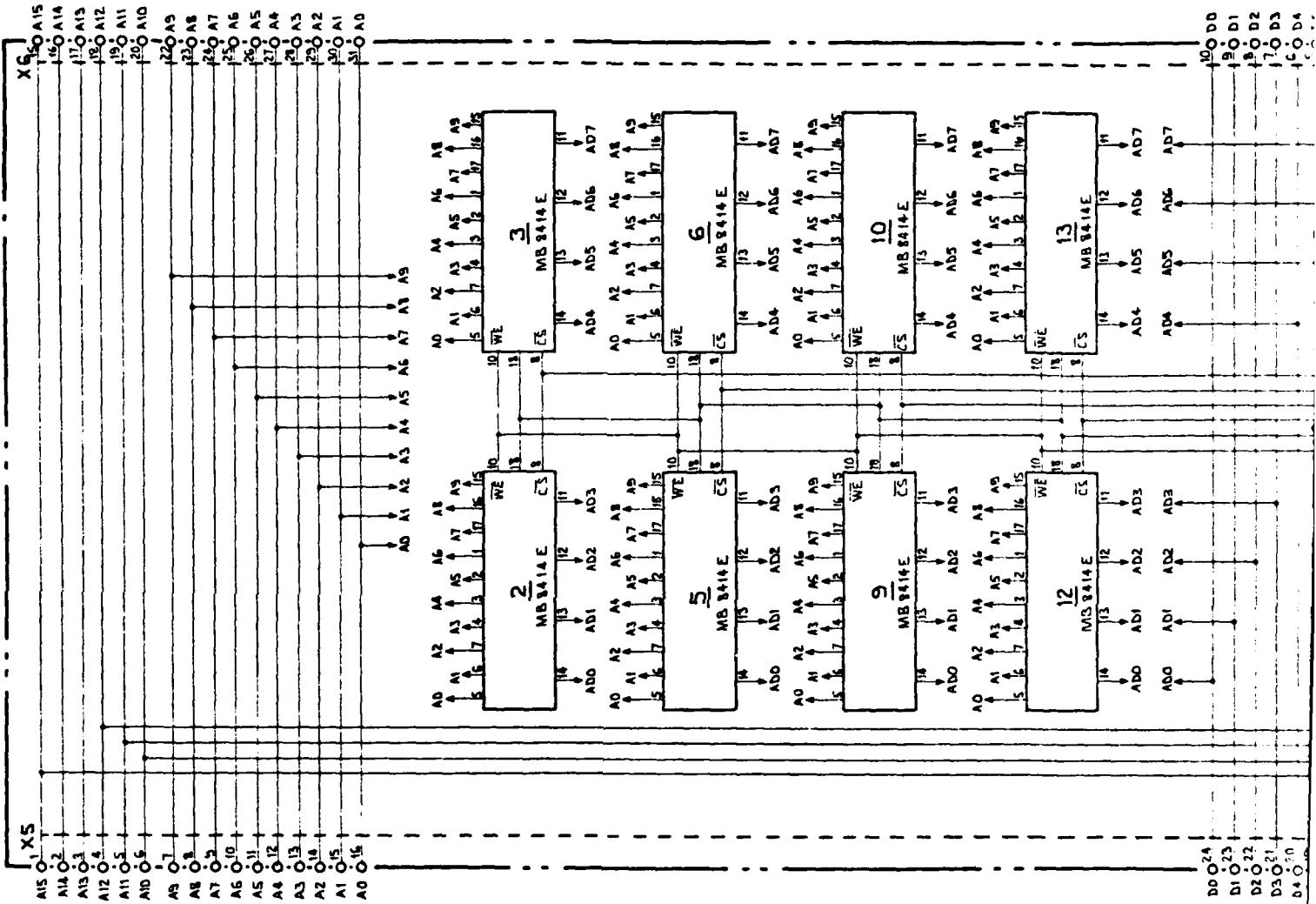


Figure 5. Microprocessor Circuit and Mathematical Processor Interface

DESCRIPTION	NO. OF PIN'S	+5V	0V	-5V	PKGE
PPI	40	26	7		SIL
USART	28	26	4		SIL
HEX INVERTER-BUFFER	14	14	7		SIL
TRI-STATE	23	15		7	SIL
INTEGRATOR	4	3		2	SIL
FLIP FLOP	16	14	7		SIL
CLIP FLOP	16	14	7		SIL
MPU	40	1	29		SIL
INTEGRATOR	14	14	7		SIL
NEGATIVE INVERTER	8	8	3		SIL
INTEGRATOR	14	14	7		SIL



REF N°	TYPE	DESCRIPTION
1	7556	TIMER
2,3,5,6,9,10	MB8414E	CMOS RAM
12,13	-	-
4	74LS00	OR-AND 2 TO 4
7	74LS138	4-OF-8 SELECTOR
8	74LS03	COMPARATOR
11	4078	NOR

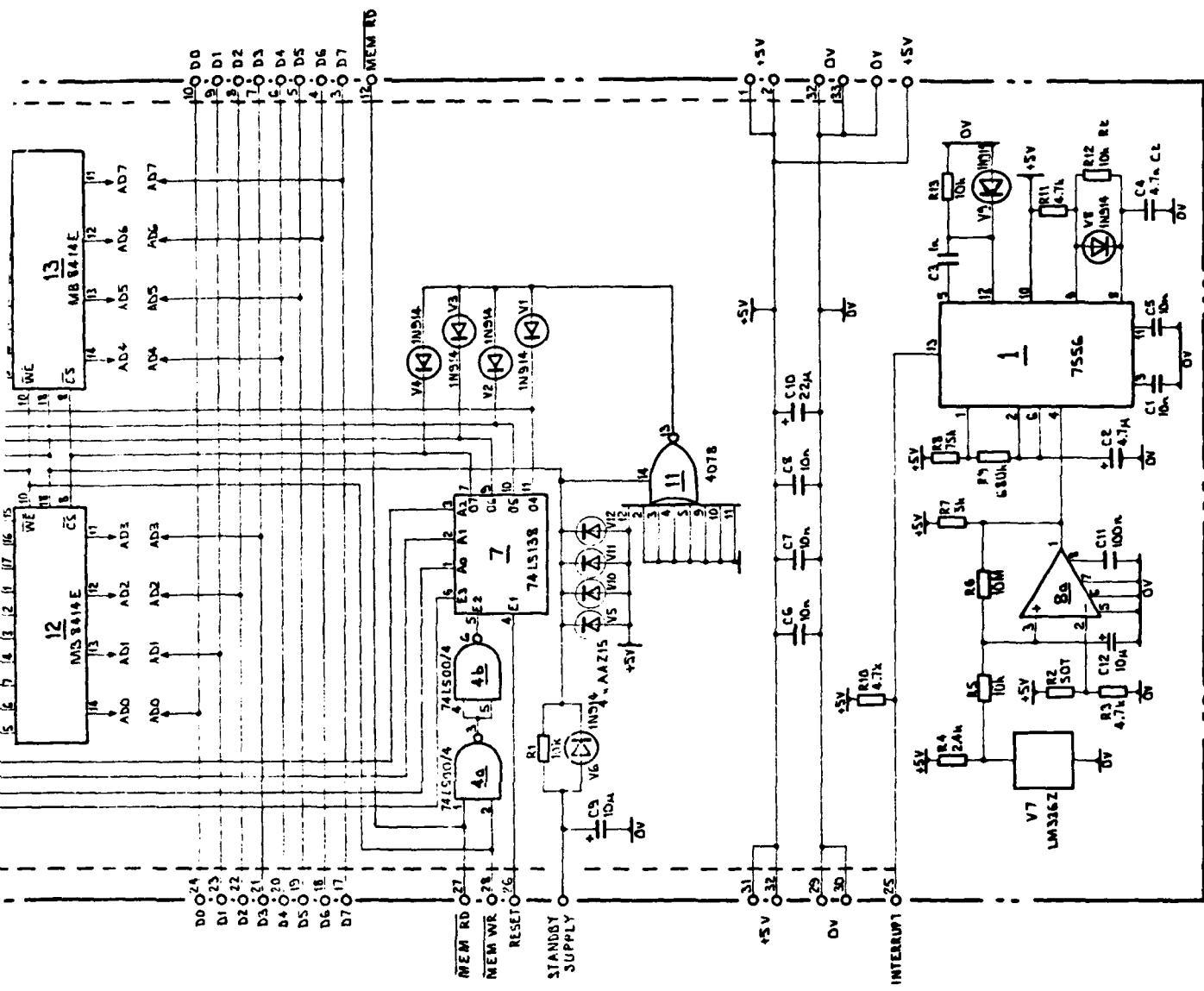
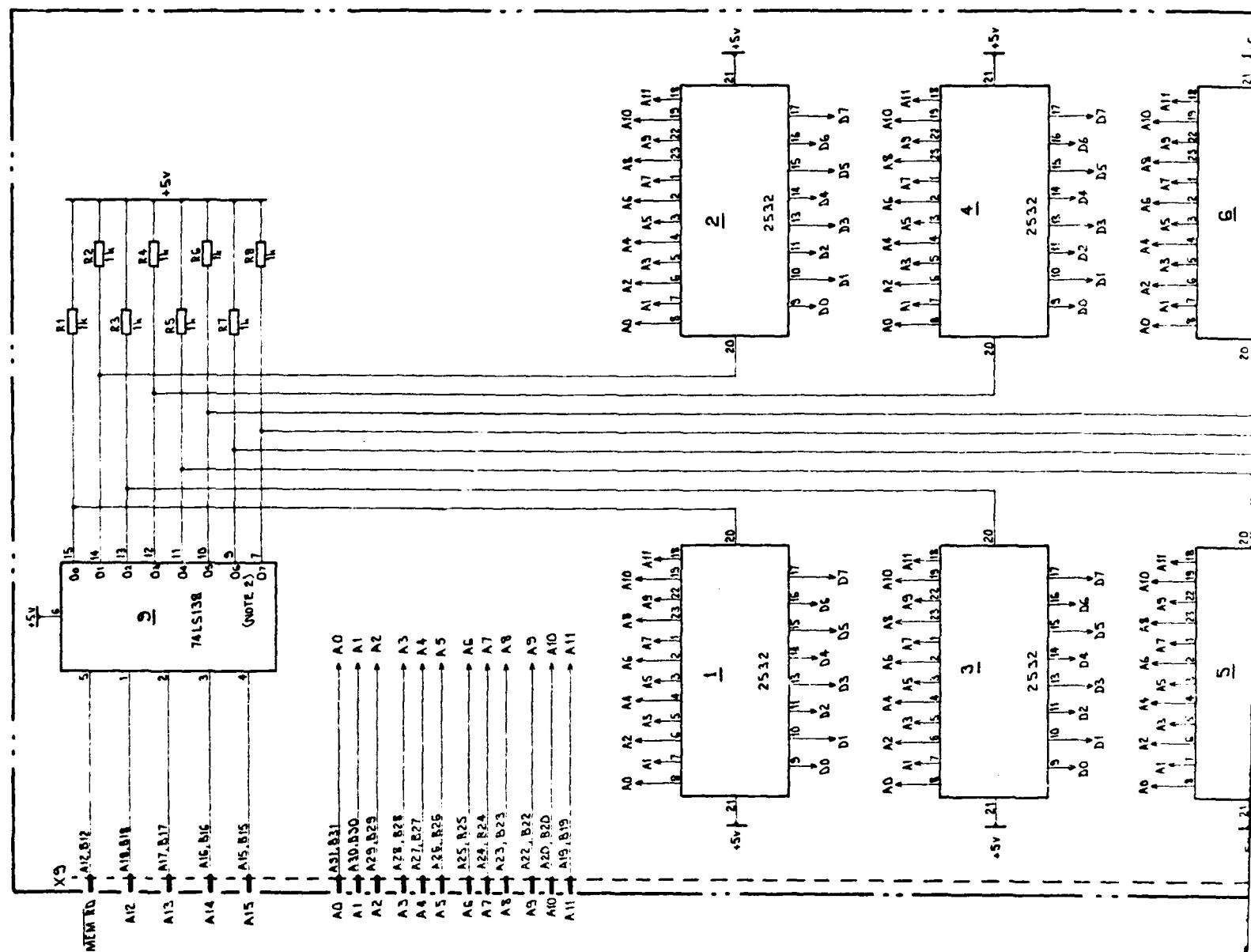


Figure 6. Random Access Memory and Low Battery Circuit

TYPE	DESCRIPTION	N# OF PINS	+5V	0V	PKG
556	TIMER	16	14	7	DIL
6414E	CMOS RAM	16		9	DIL
LS500	DECODE 8 TO 16 INPUT	16	14	7	DIL
LS138	1 OF 8 SELECT	16	7	8	DIL
7493	COMPARATOR	8	8	4	DIL
7478	NOR	16		7	DIL



REF NO	TYPE	DESCRIPTION	NO OF PINS	+5V	2V	0V
1 to 8	2532	8L EPROM	24	24	12	12
9	74LS138	ADDRESS DECODER	16	16	8	7

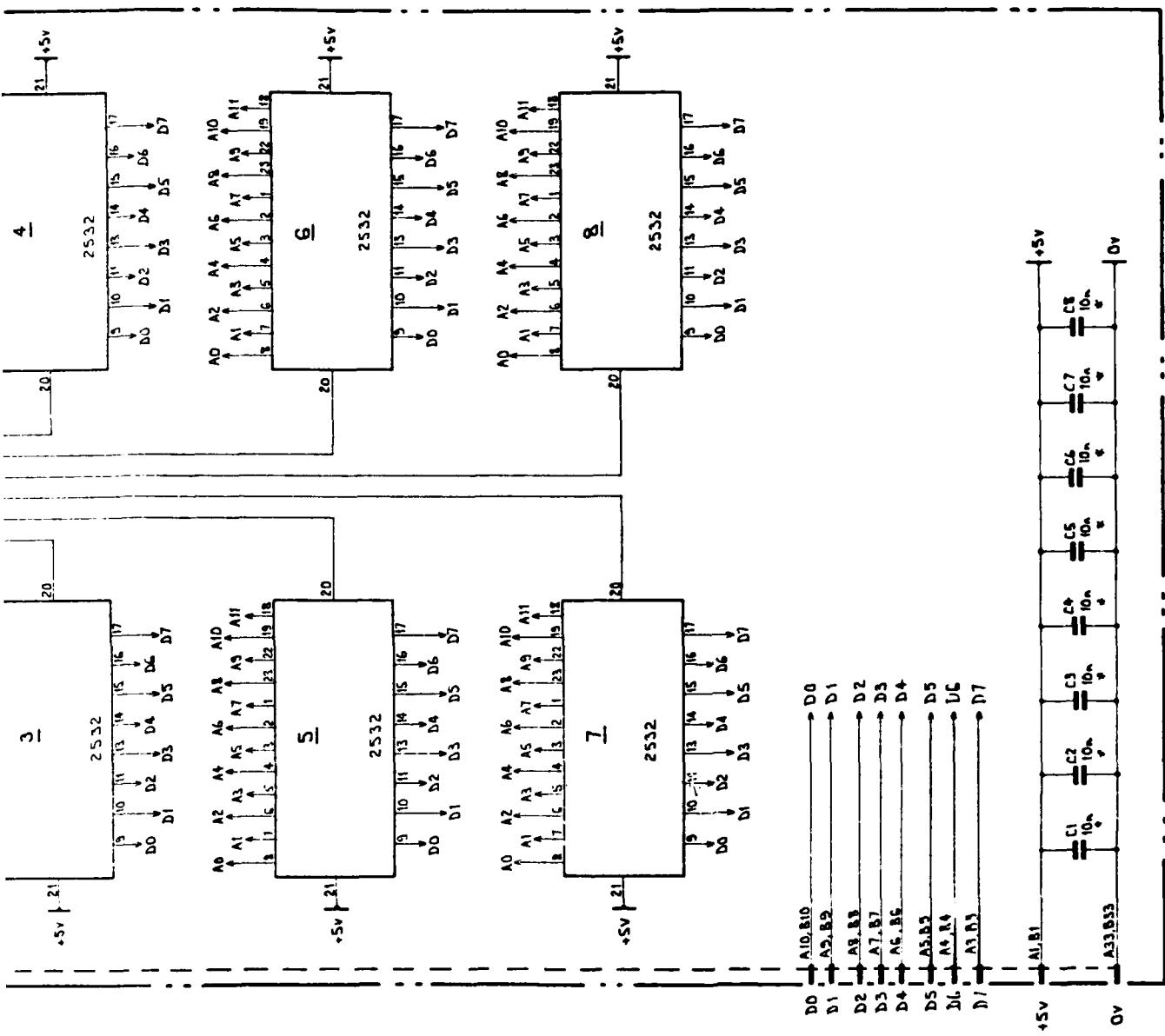
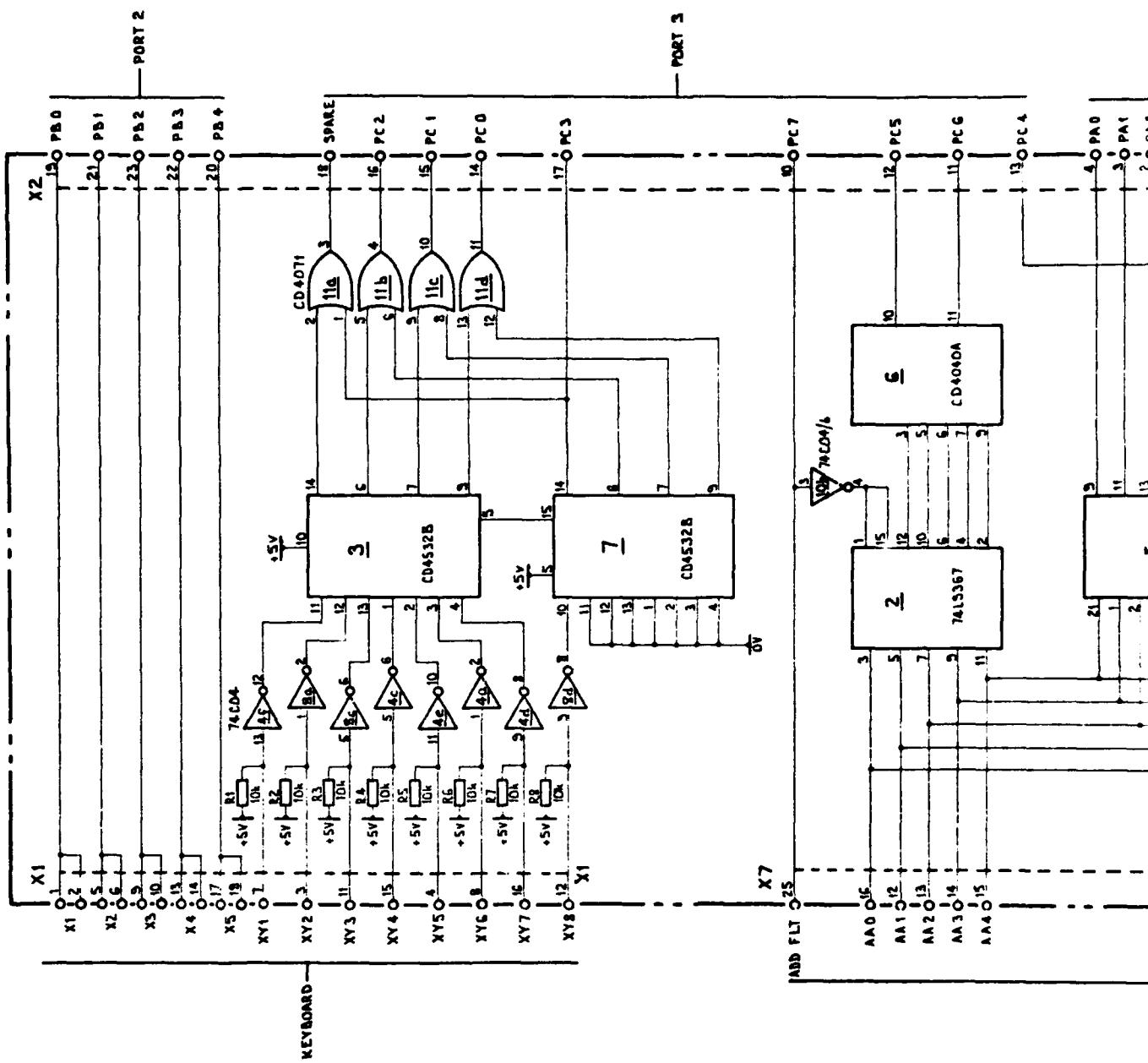


Figure 7. Program Memory Circuit

DESCRIPTION	No OF PIN(S)	+5V	CV	PKGE
EFROM	24	24	12	DEL
RESS DECODER	16	16	8	DEL

NOTES:- 1. WRITE ENABLE WE PULSE MUST BE  $> 50\mu\text{SECONDS}$



REF NO	TYPE	DESCRIPTION	PCF EPC
1	2210	HEX IN	24
2	74LS167	TRI STATE BUFFER	16
3,7	CD4532B	PRIORITY ENCODER	16
4,8,10	74C04	HEX INVERTER	16
5,9	6551	CMOS RAM	22
6	CD4040C	COUNTER	16
11	CD4071	BUFD OR GATES	16

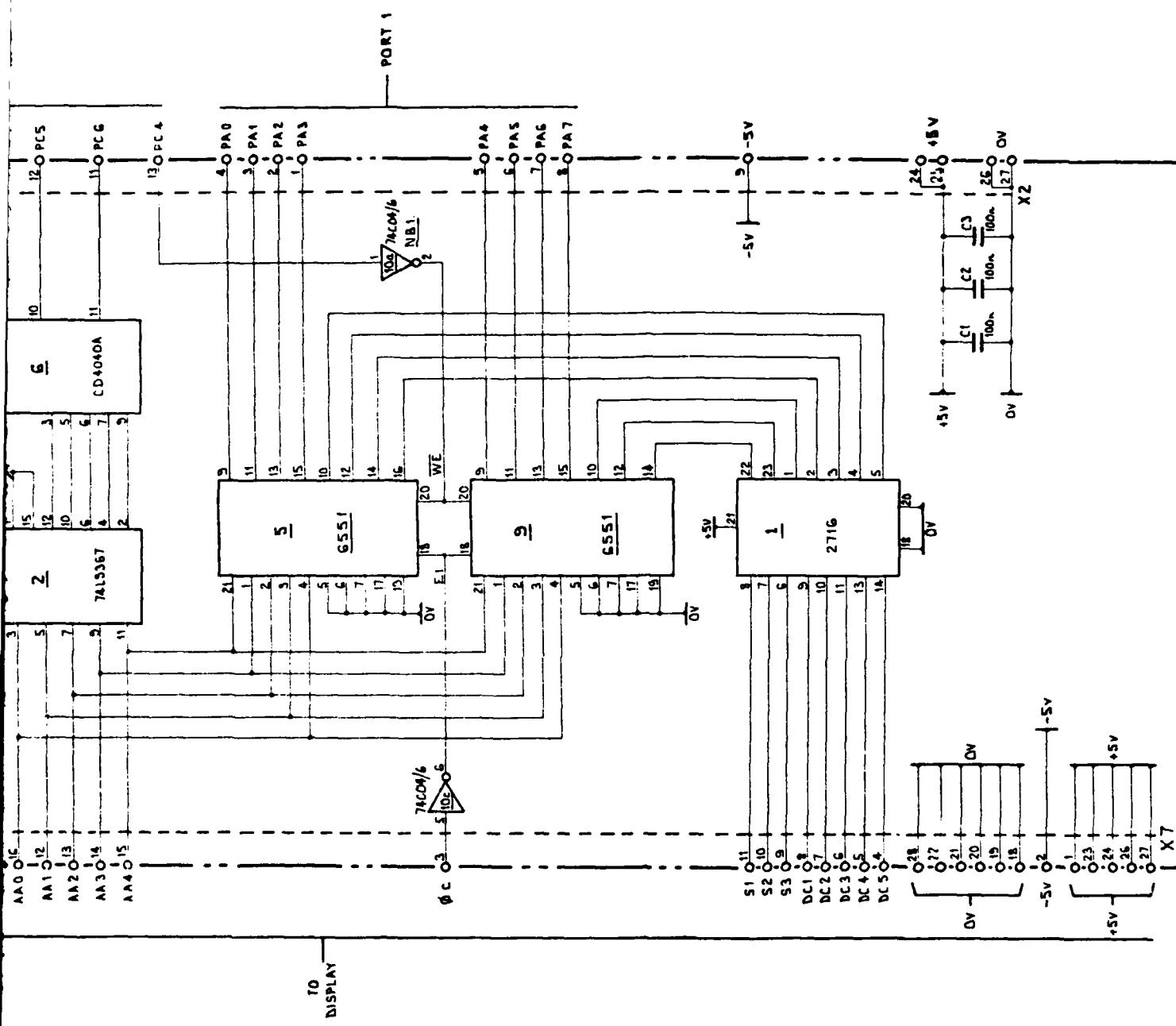


Figure 8. Display and Keyboard Interface Circuits

PE	DESCRIPTION	NO OF PINS	+5V	0V	-5V	PKG
1	EEPROM	24	24	17	-	SIL
157	TRI-STATE 8-BIT REG	16	16	8	-	SIL
218	PRIORITY ENCODER	16	16	8	-	SIL
24	HEX INVERTER	14	14	7	-	SIL
61	4017 PAM	22	22	8	-	SIL
140	DECODERS	16	16	8	-	SIL
171	BUS OR GATE	16	14	7	-	SIL

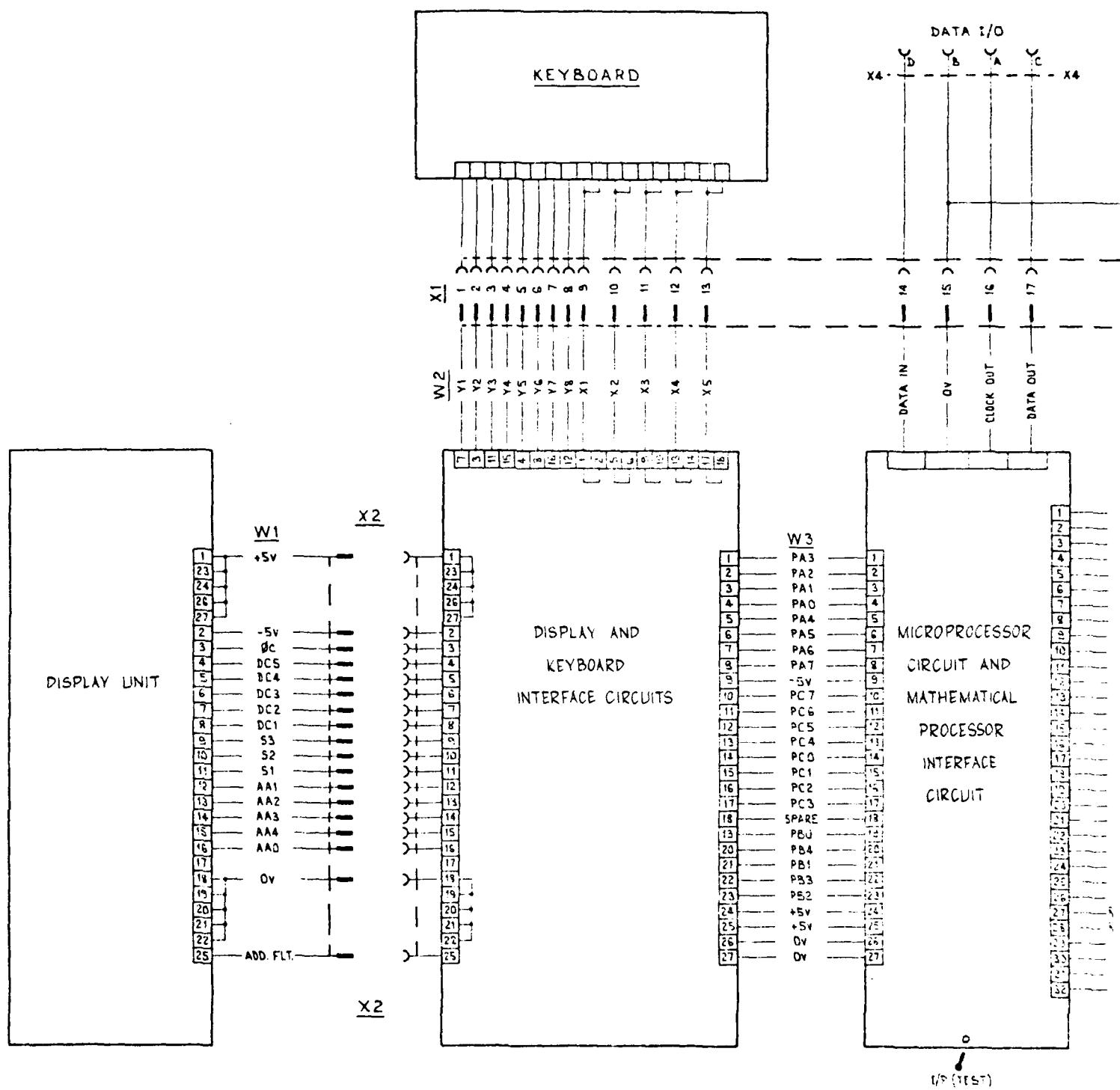
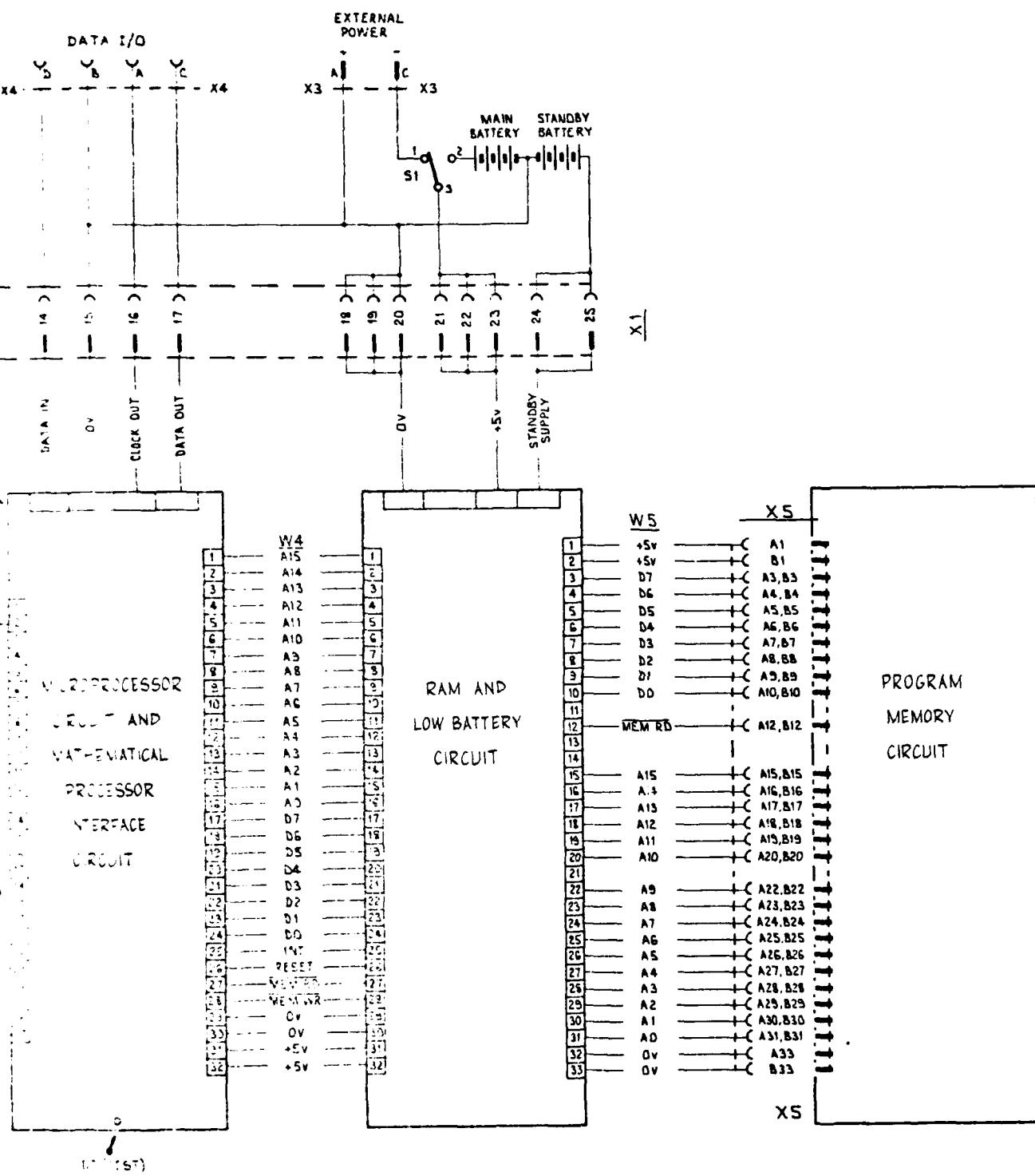


Figure 9. Wiring Diagram



## 9. Wiring Diagram

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A microprocessor based calculator is described which has been designed to provide assistance in determining aiming coordinates for Mortar fire control. However by changing the keyboard overlay and the software the calculator can be used for a variety of applications including Artillery and Armour fire control.

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